High Energy Stellar, Protostellar and Protoplanetary Physics

Extracts from Science Case and Performance Requirements for Constellation-X

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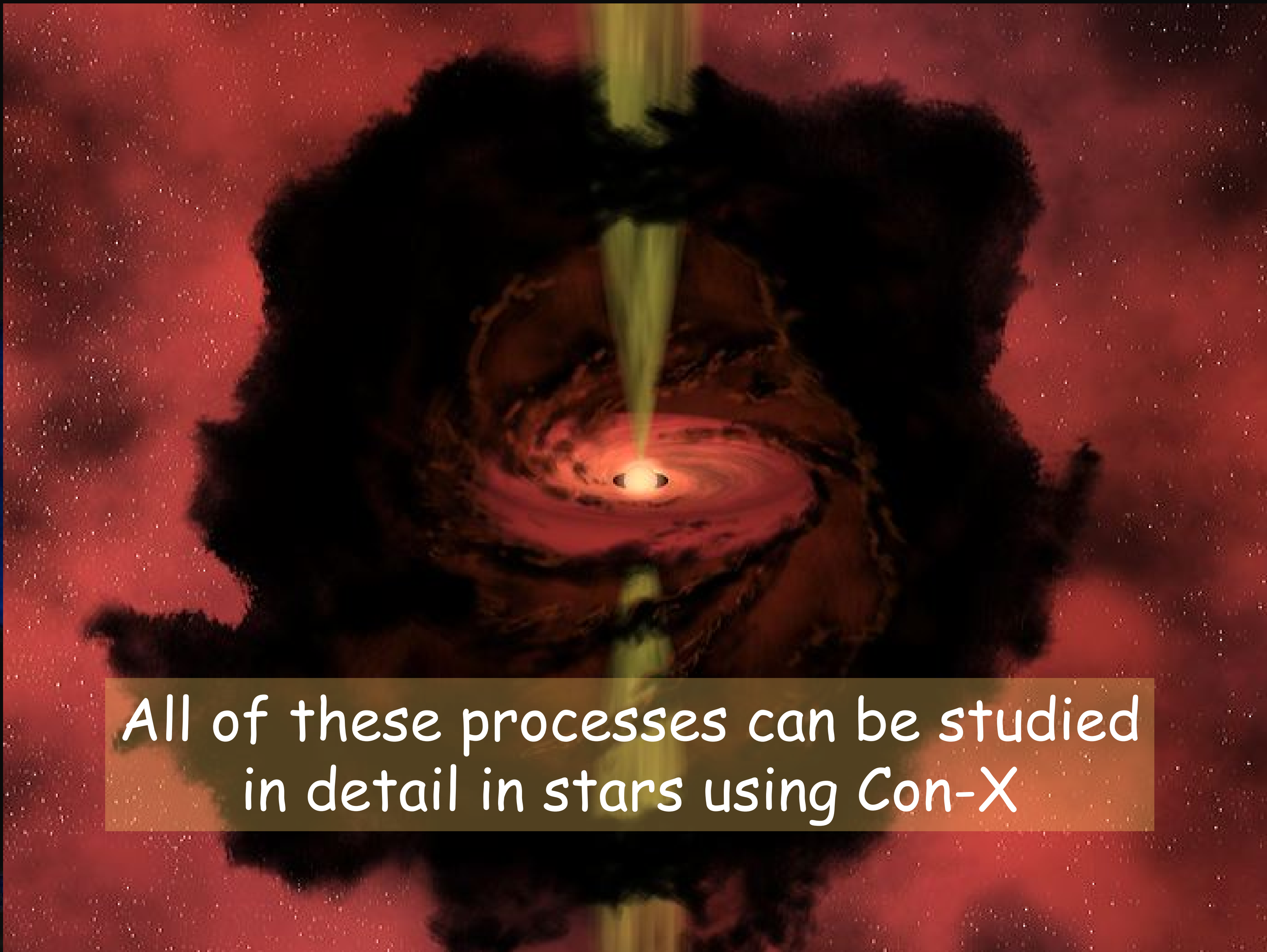
Et al

FST 19 Dec 2006 GSFC

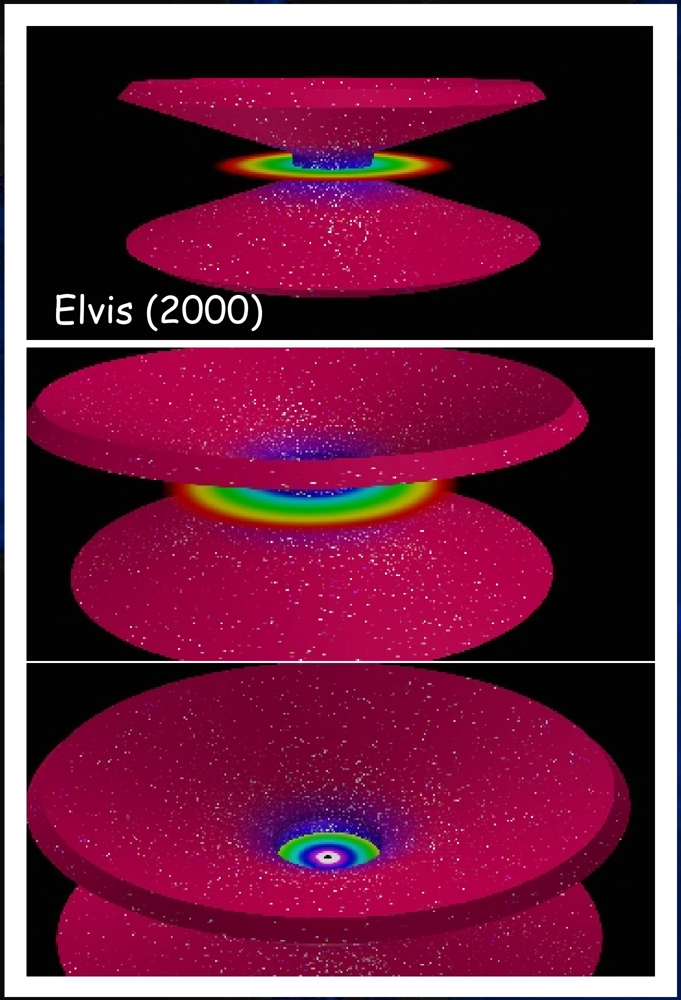
Mainstay Con-X Science

- Accretion physics
- Disks; fluorescence, reverberation mapping
- Jets, outflows
- Energy cycles; Feedback; Magnetic reconnection
- Relativistic particles, acceleration



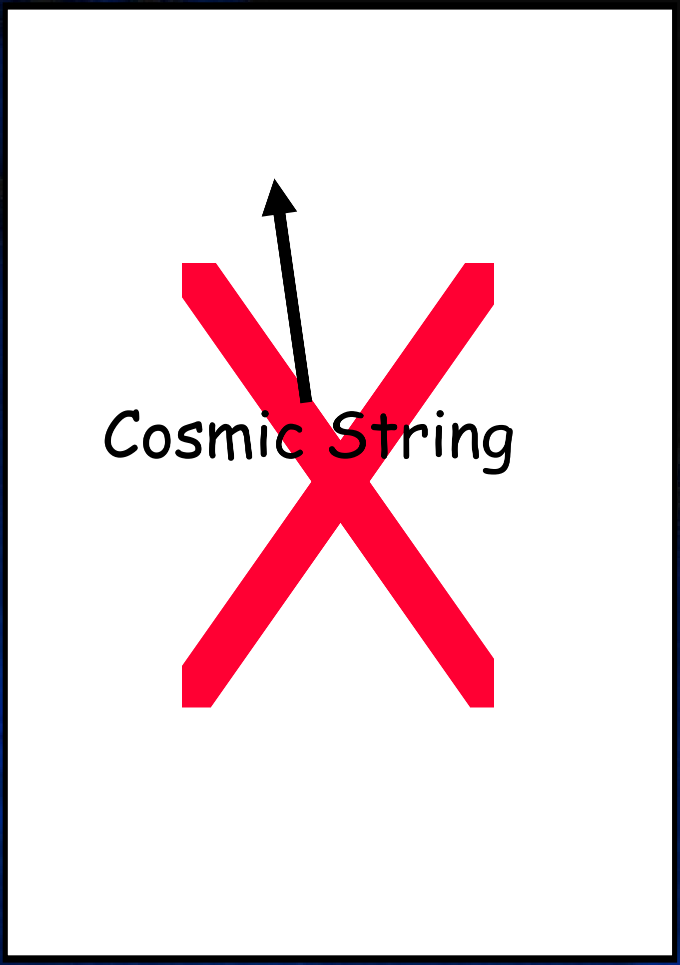
All of these processes can be studied in detail in stars using Con-X

Knowing Your X-ray Source



AGN

Yo-Yo

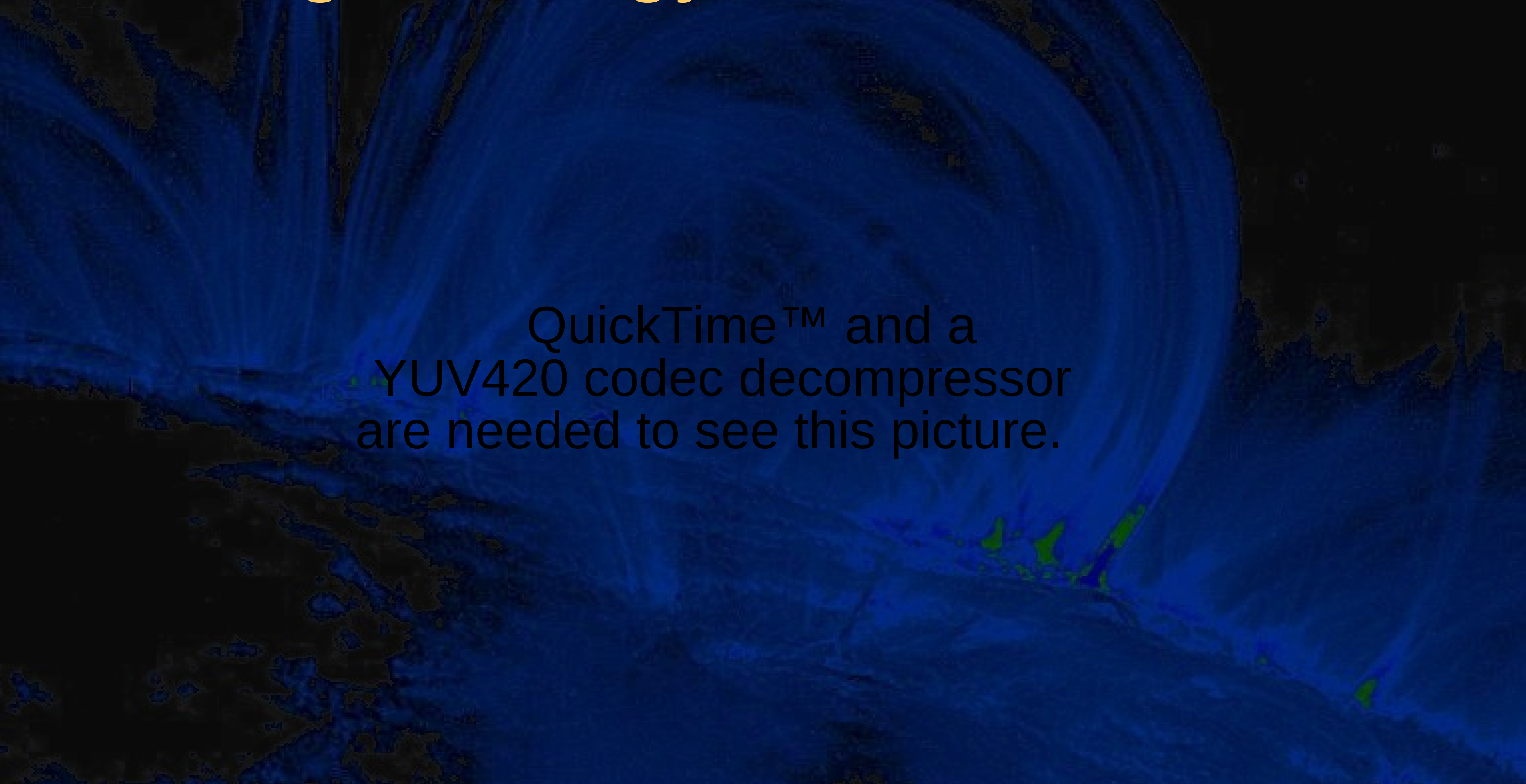


Outline

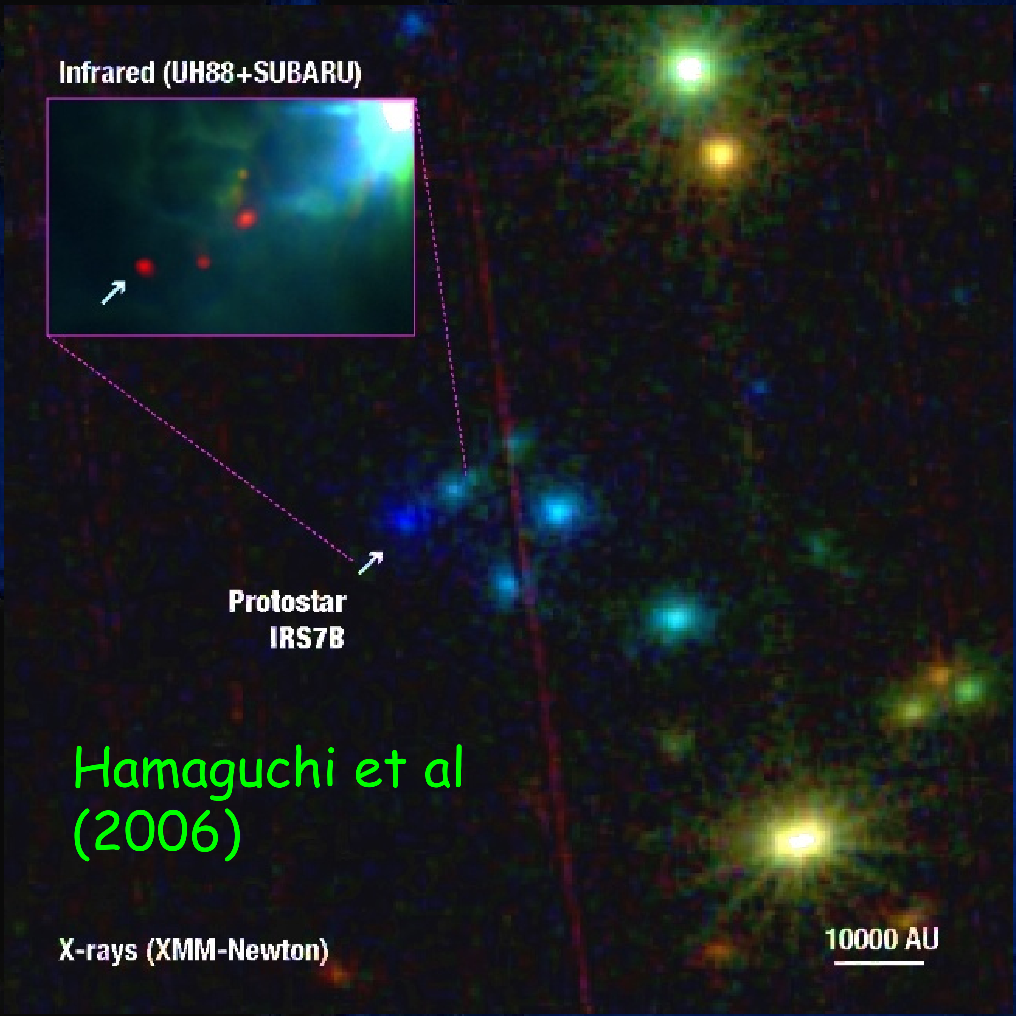
- Origins: the formation of stars and planets, and their high energy environments
- Hot, magnetised plasmas in brown dwarfs, main-sequence and evolved stars
- Magnetic flares: prototypes of energy lifecycles and release (see R. Osten talk next)
- Outflows and shocks in massive stars

Origins: The Formation of Stars and Planets and their High Energy Environments

Origins: The Formation of Stars and Planets and their High Energy Environments



When do protostars start generating X-rays? - Penetrating B-field probe

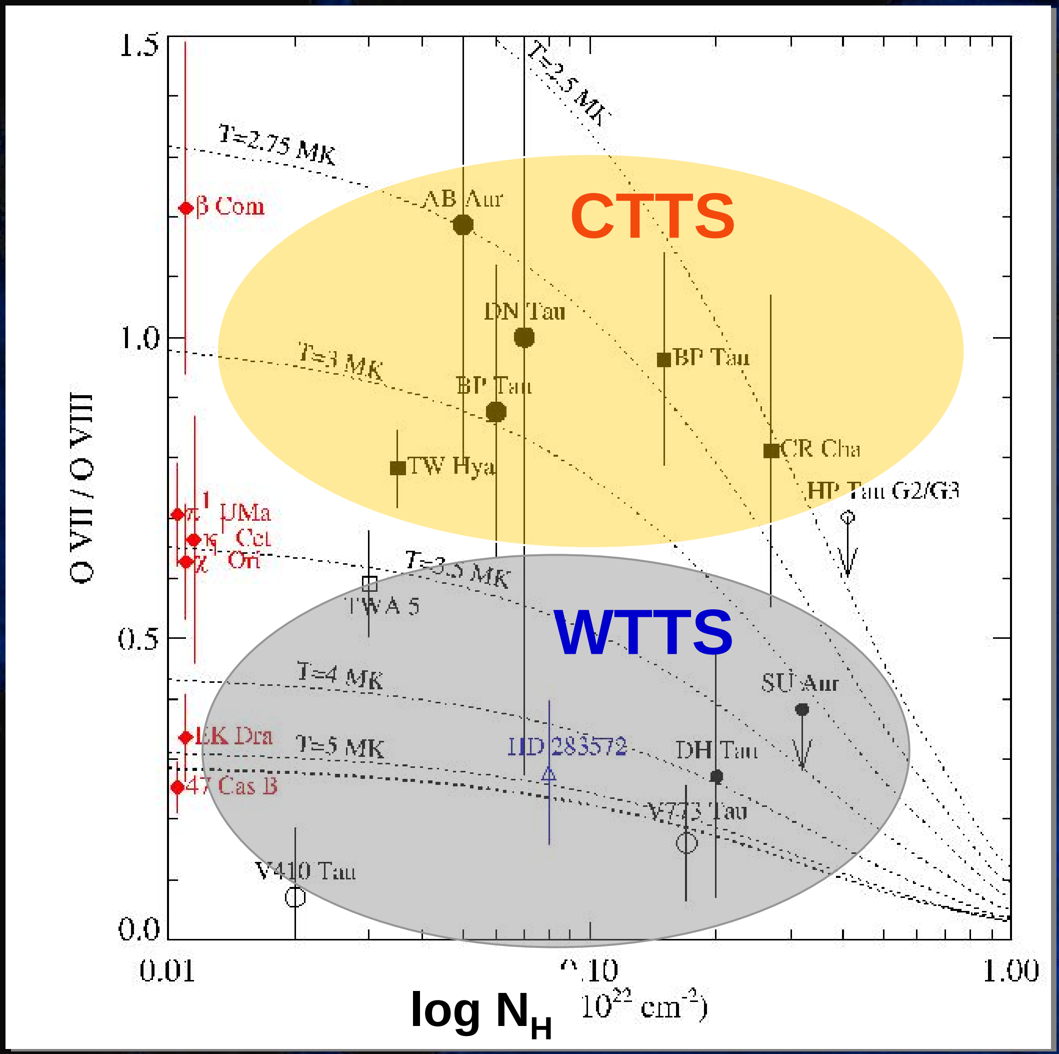


Hamaguchi et al (2006)

- Earliest protostars "class 0" ~ 10^4yrs old
  - Cold 10^3-10^4AU envelope, nascent core, collimated outflows, jets
- X-rays => ionisation source, dynamo, magnetic fields; link to jets?
- Difficult to detect; RCrA IRS7b best evidence to date
- **Need sensitive Con-X surveys >3 keV**

Soft Excess in Accreting T Tauris

(Telleschi et al 2006)



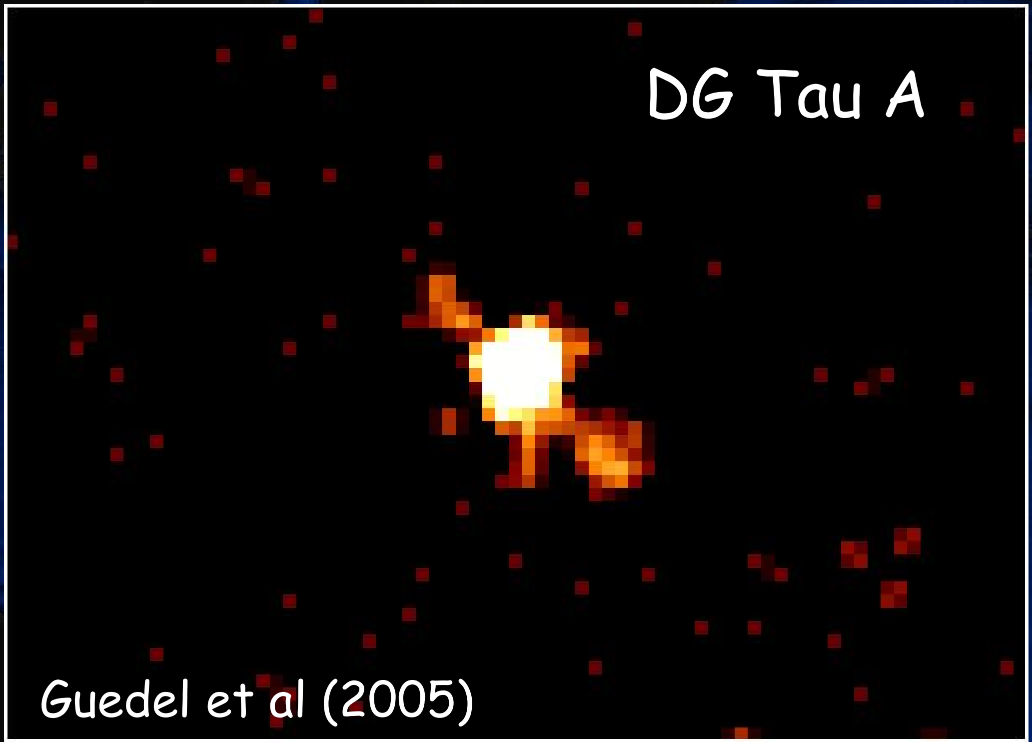
- *OVII/O VIII Ly α*
  - *low in CTTS*
  - *high in WTTS*
- *separate, excessive cool (1-3 MK) component in accreting TTS*

accretion-related cool plasma?

Soft Excess: Probing Accretion Shocks

- TW Hya cool emission from ballistic accretion shock rather than corona
  - direct study of accretion process; accreting gas composition
- High n_e so far only detected on 2 other stars (BP Tau, V4046 Sgr)
- **Limits of Chandra and XMM sensitivity**
- **Need R>600 eg to deblend Ne IX & FeXIX (>1000 to distinguish)**

Soft Excess: X-rays from T Tauri Jets



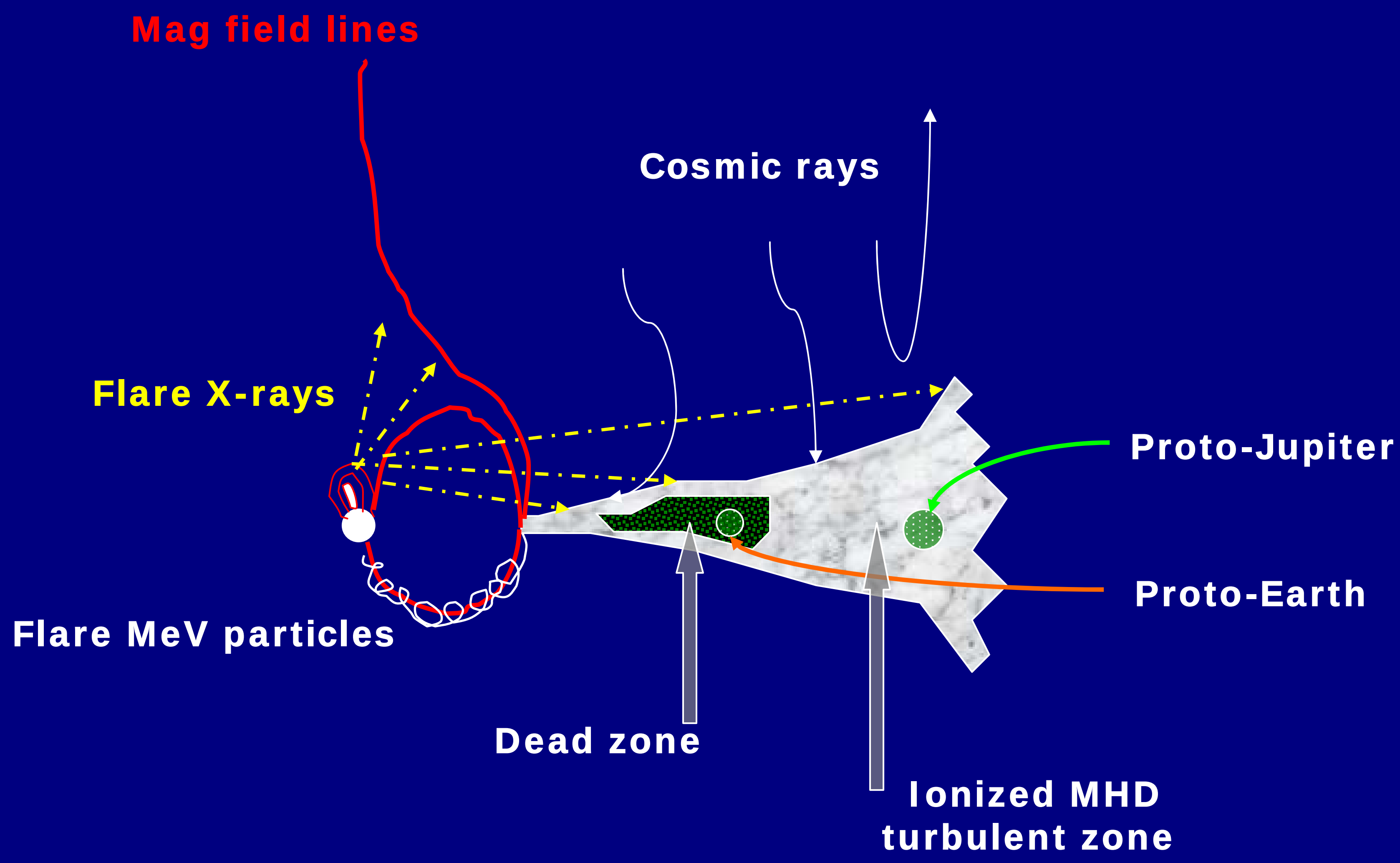
- X-rays appear to be formed in shocks from base of jet to ~500AU
- V_s~300km/s (similar to accretion velocities), $n_e \sim 10^3 - 10^5$ cm^{-3}

Need to resolve Ne, O He-like ions --> densities
Need velocity resolution to see ~100 km/s

Con-X Studies of T Tauri Accretion and Jets

- Soft excesses appear quite common in T Tauri stars
- Chandra and XMM-Newton can only reach brightest few objects
- Jets and accretion have identical signatures at low resolution
  - Need to resolve Ne, O He-like ions --> densities
  - Need velocity information **at low E** for ~100 km/s to probe jet physics

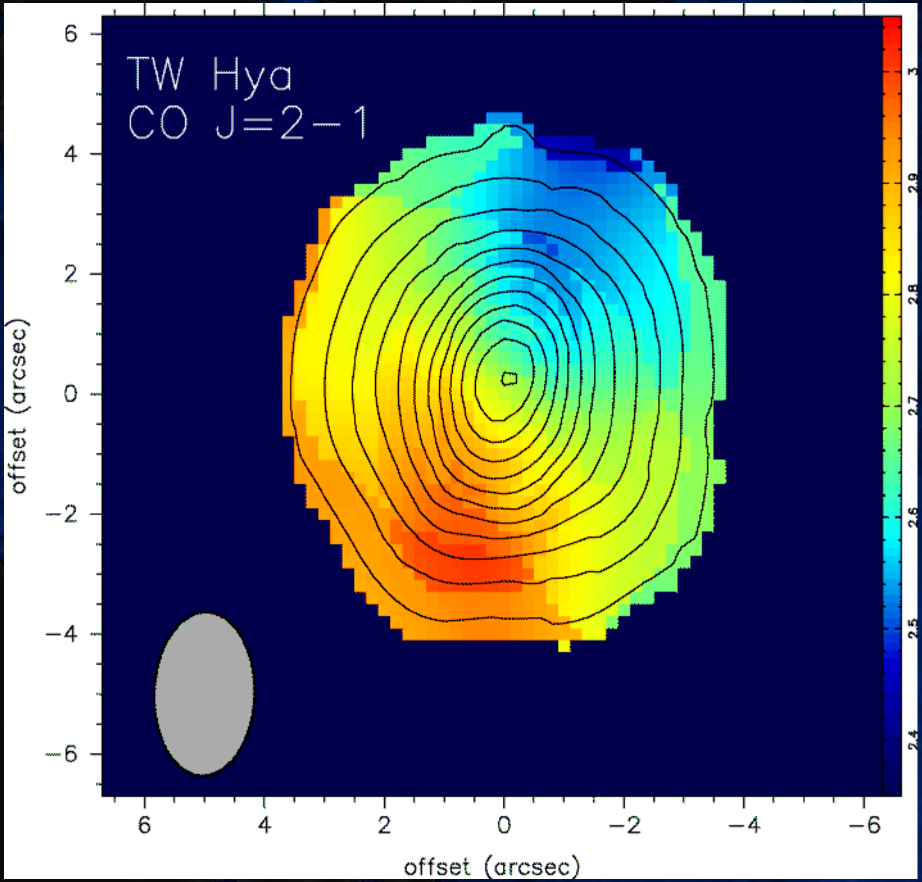
High energy processes & protoplanetary disks

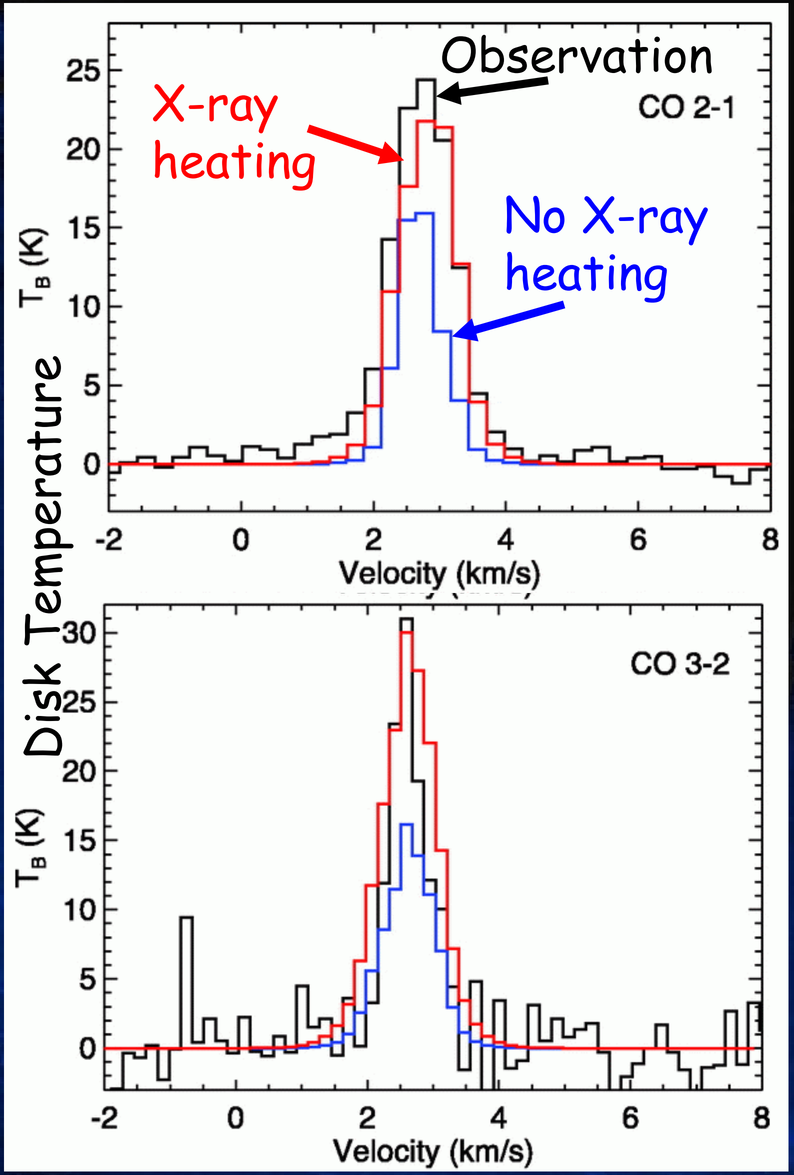


Feigelson 2003 [2]

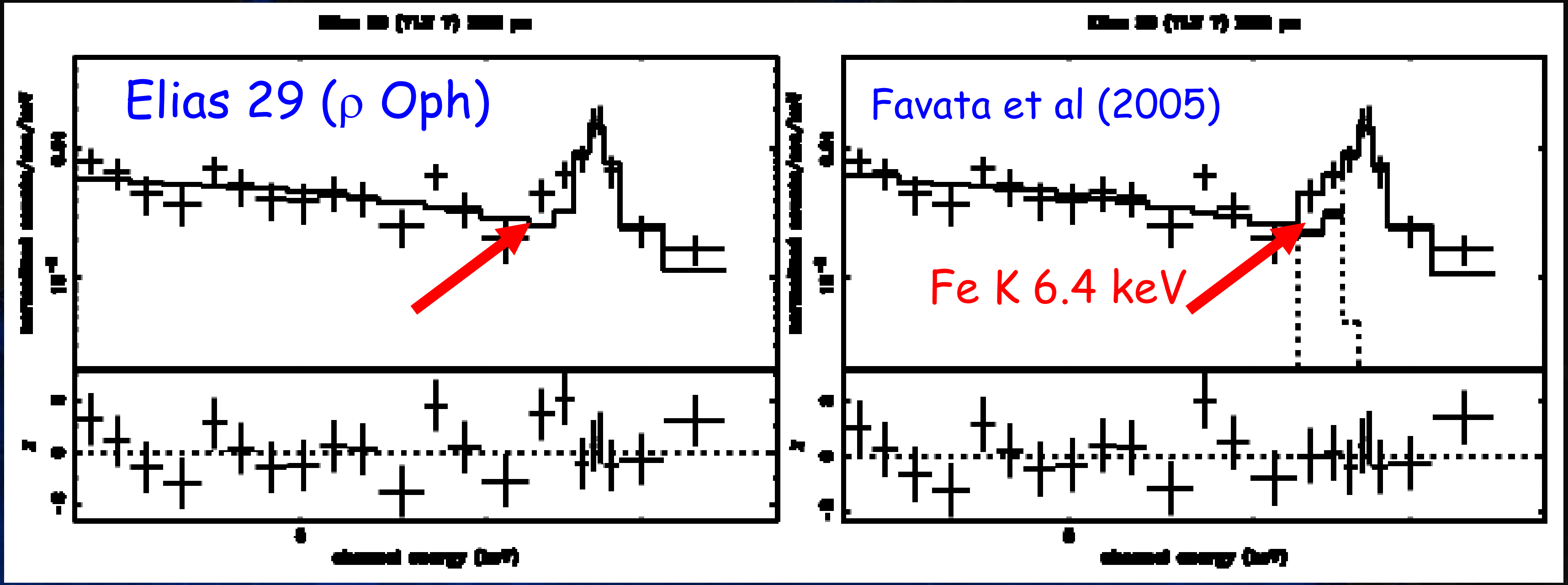
SMA Detection of X-ray Disk Heating

(TW Hya; Qi et al 2006)

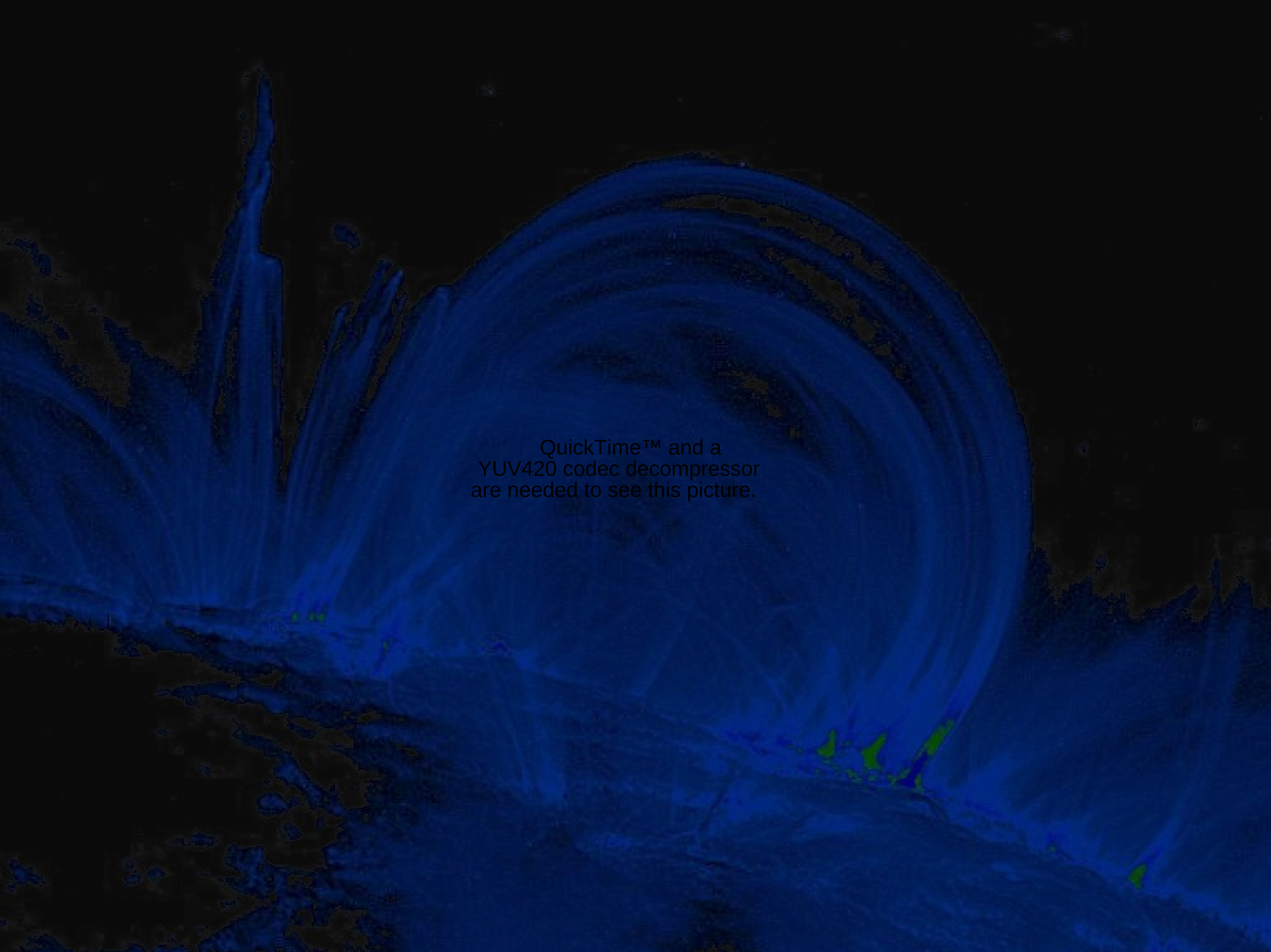




Protoplanetary Disk Fluorescence



- Inner-shell Fe ionisation by X-irradiation ==> 6.4 keV FeK_α
- FeK_α sources preferentially deeply embedded with near-IR excesses; i.e. very young systems with heavy disks
- Direct evidence for protoplanetary disk irradiation


QuickTime™ and a
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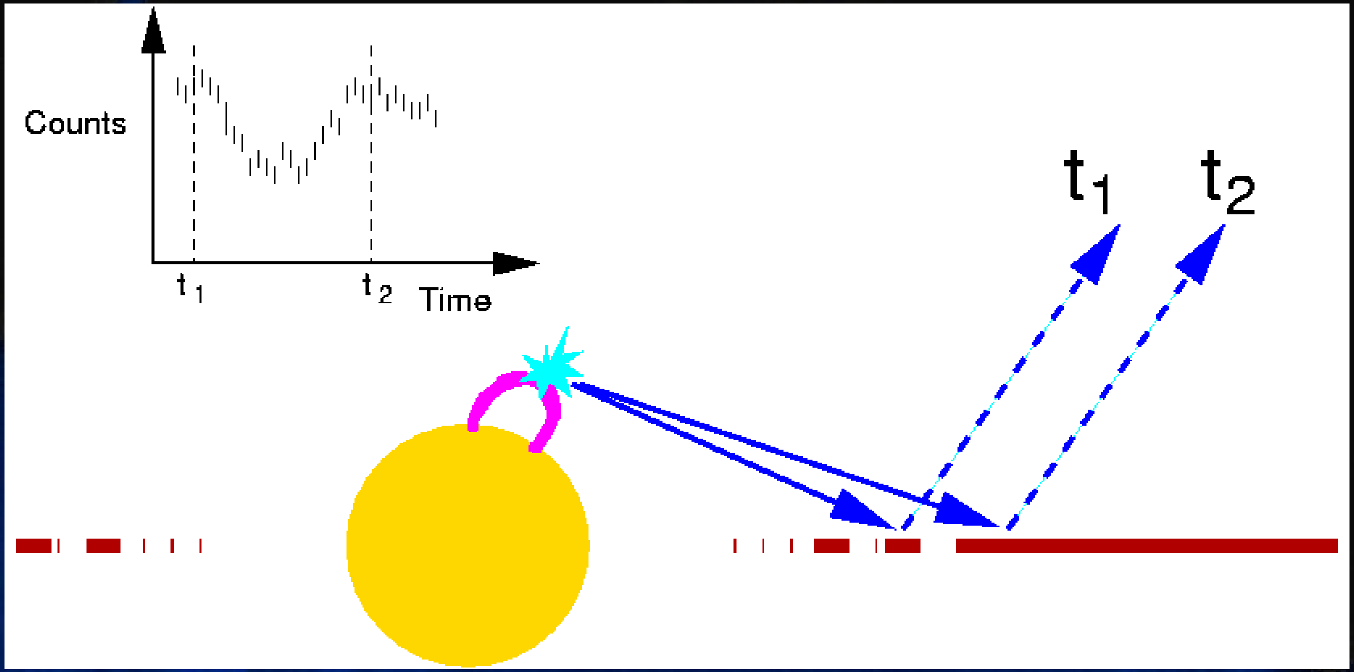
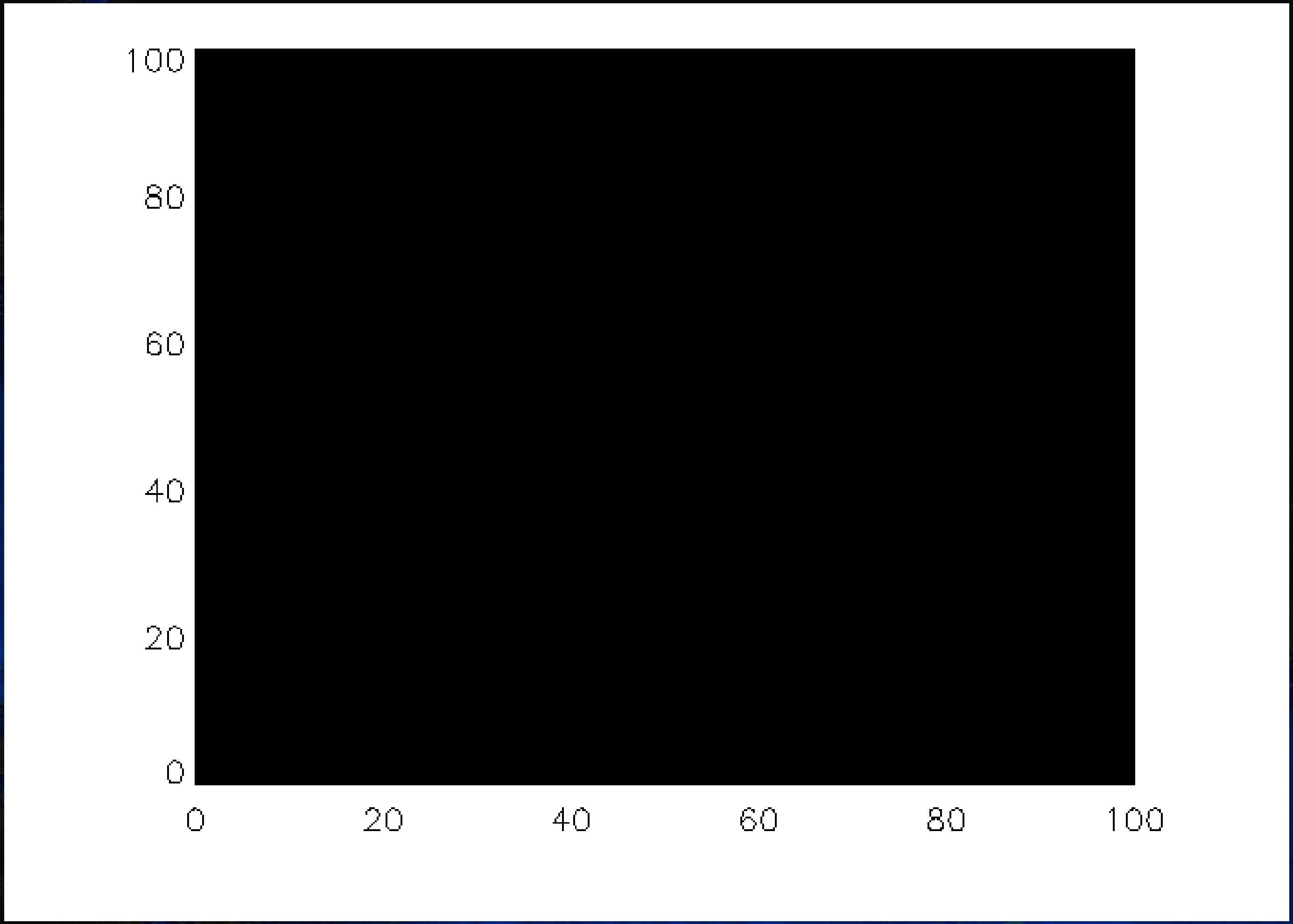
are needed to see this picture.

Protoplanetary Disk Fluorescence



- Unlike most AGN,XRB cases, geometry and emission mechanisms are well-constrained
- Use to probe **inner disk radius**, **protoplanetary gaps** during flares
- Elias 29 Fe K strength $2x10^{-6}$ph/cm2/s quiescent, x10 in flare ==> Con-X sees 10 cts/100s in flare

Fe K Disk Fluorescence (Ercolano & Drake 2007)

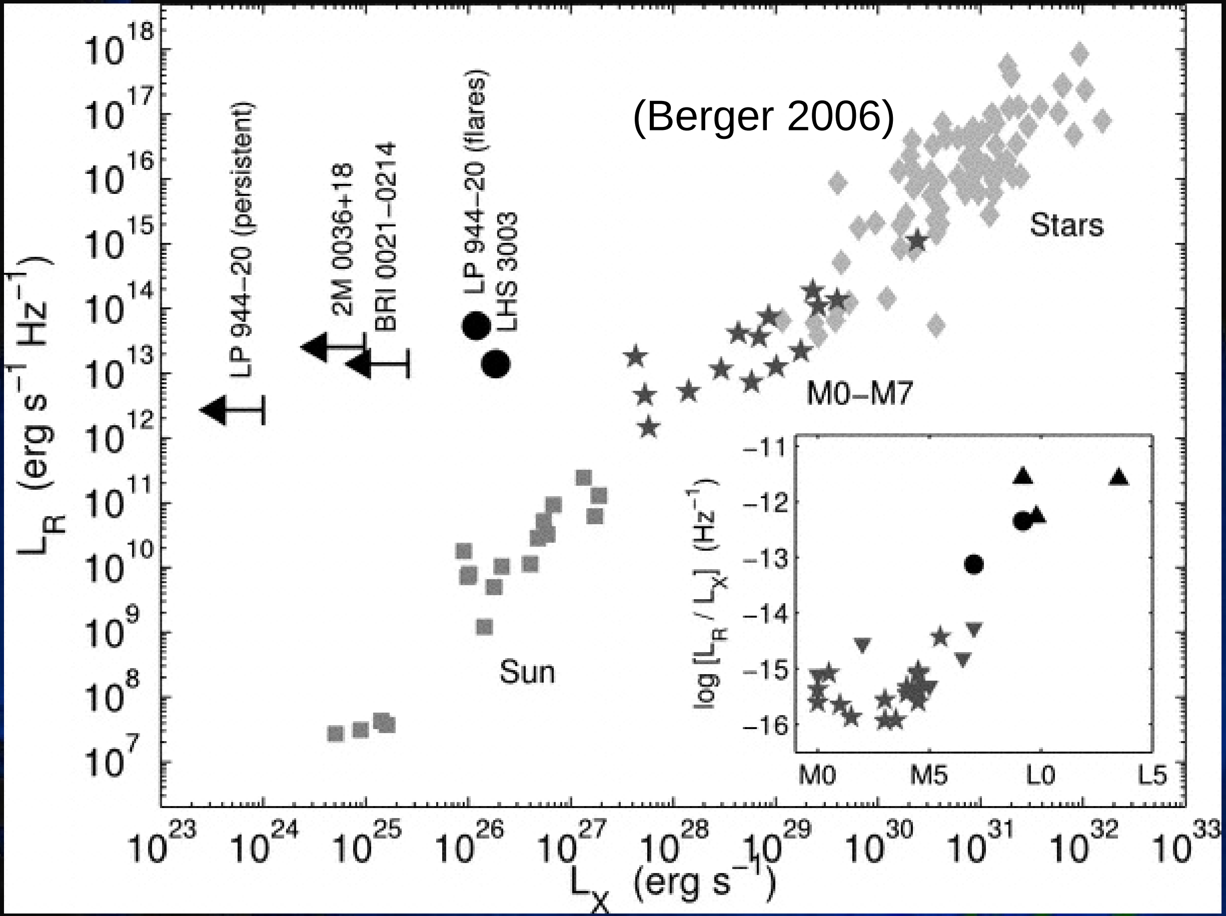


Monte Carlo simulation of Fe K fluorescence of protoplanetary disk illuminated by impulsive flare

Hot, Magnetised Plasmas in Brown Dwarfs, Main-Sequence and Evolved Stars

- Very low mass stars & brown dwarfs currently inaccessible to detailed study
  - No tachocline; near neutral atmospheres: how do dynamos and magnetic activity work? Con-X --> B field structure
- Coronal Doppler Imaging: testing dynamo models and magnetospheric accretion

Brown Dwarfs as Particle Accelerators

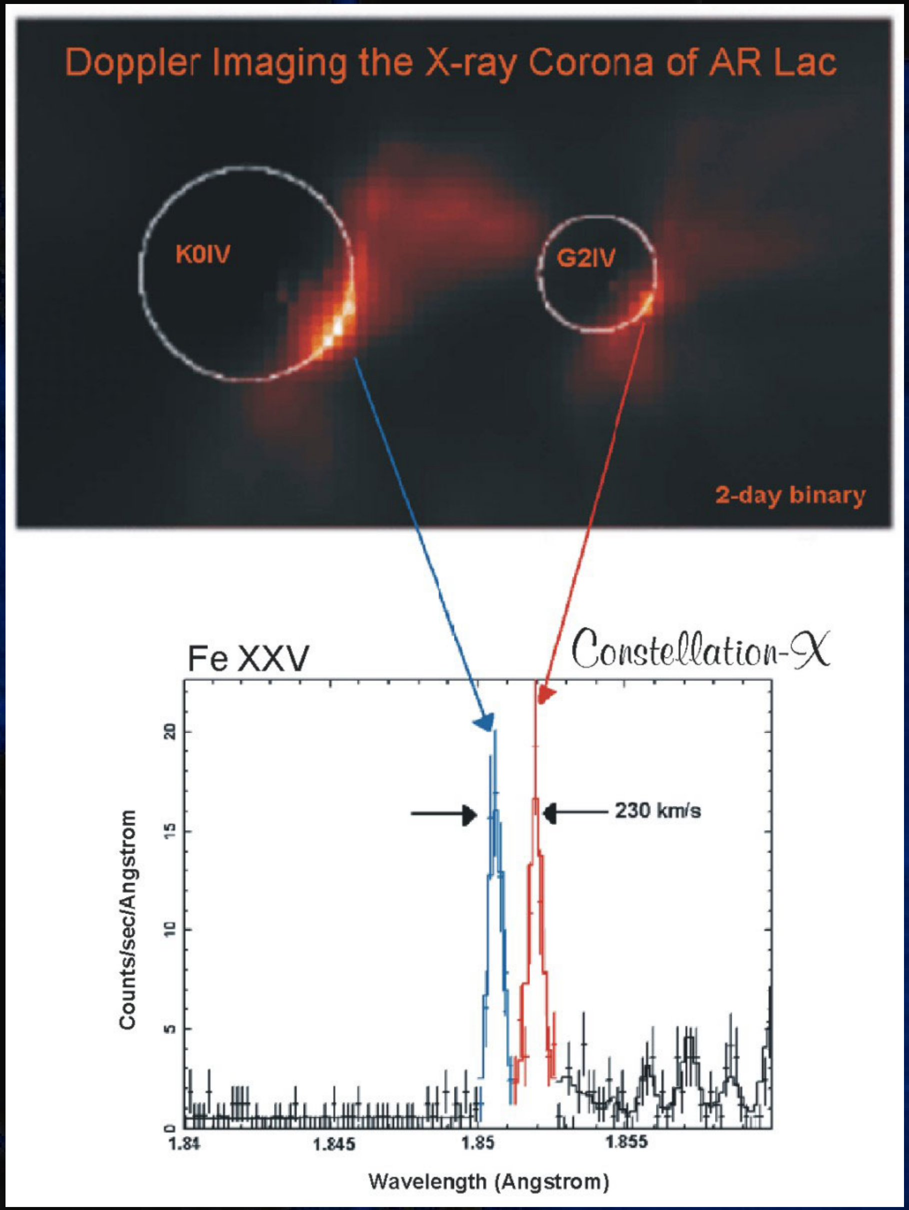


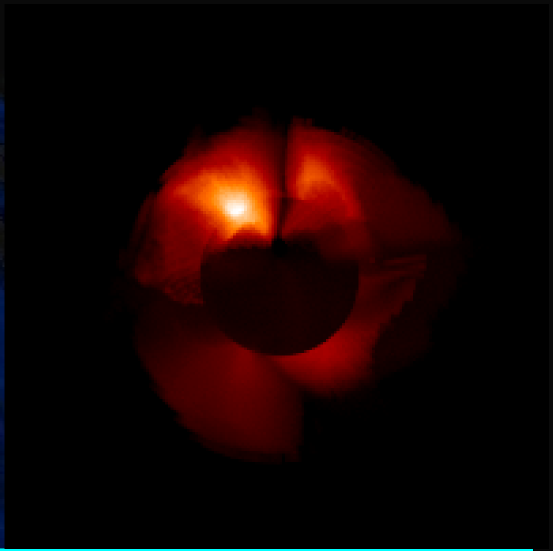
L_R/L_X shows rapid rise at M7 (T_{eff} ~2600K)

Con-X can provide plasma diagnostics to infer B field properties;

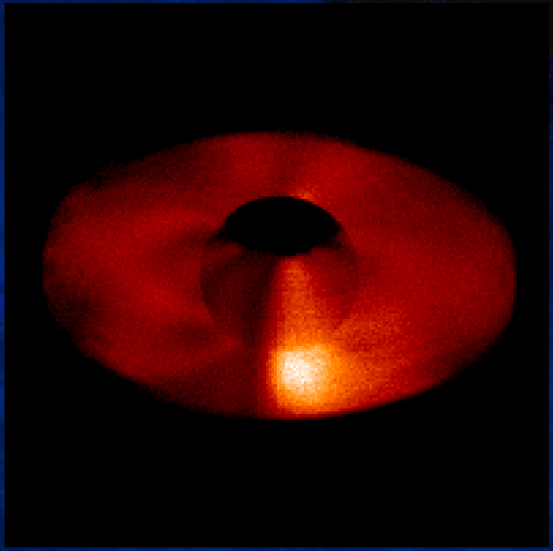
Are energetic particles related to plasma heating?

Con-X Coronal Doppler Imaging





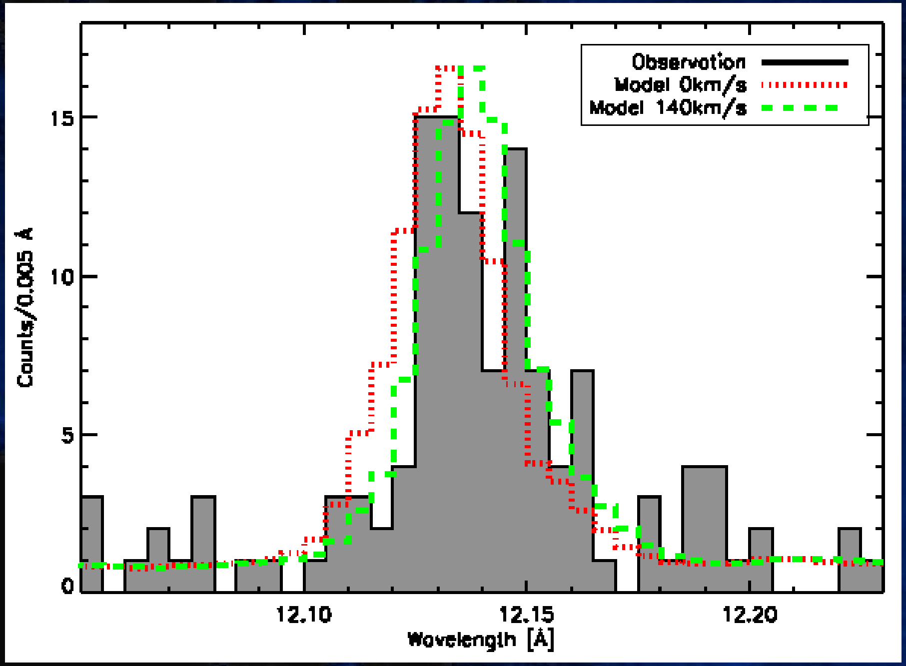
AB Dor K0 V; P_{rot}=0.5d



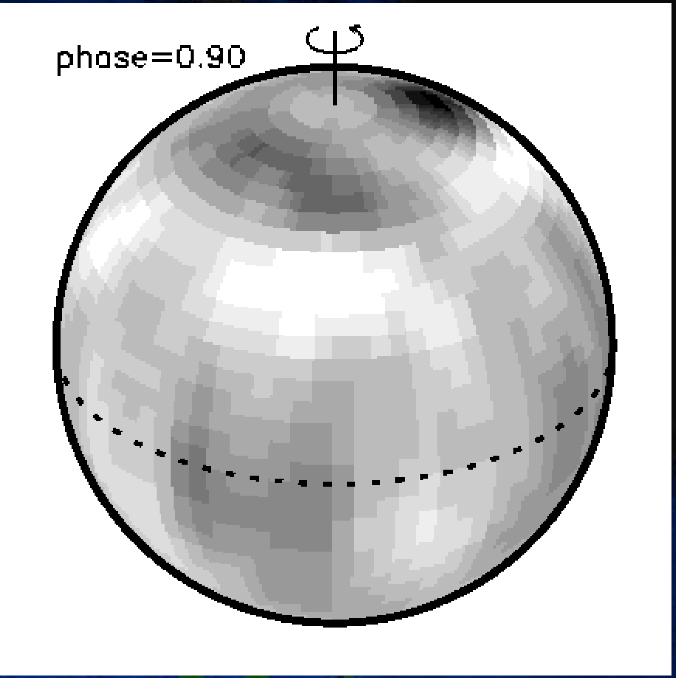
Mid-latitude Structures on FK Com

(G5 III vsini=160 km/s) (Drake et al 2006)

Chandra HETG 50ks

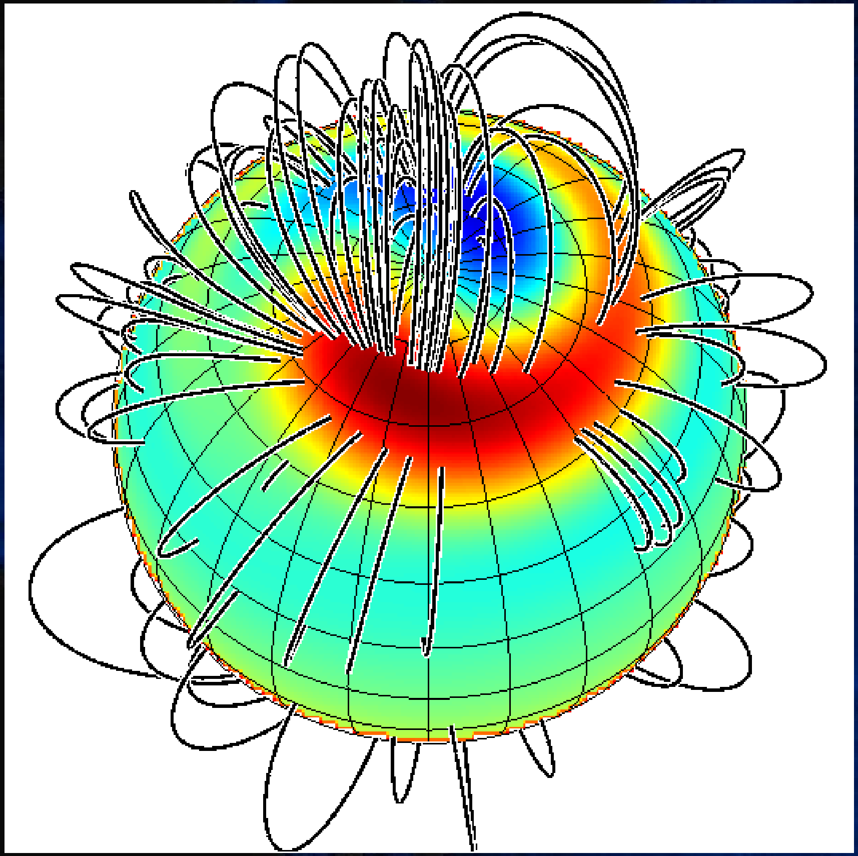


Contemporaneous Surface Doppler Image



- Redshift of ~140 km/s indicates mid-latitude structure, possibly associated with surface spots

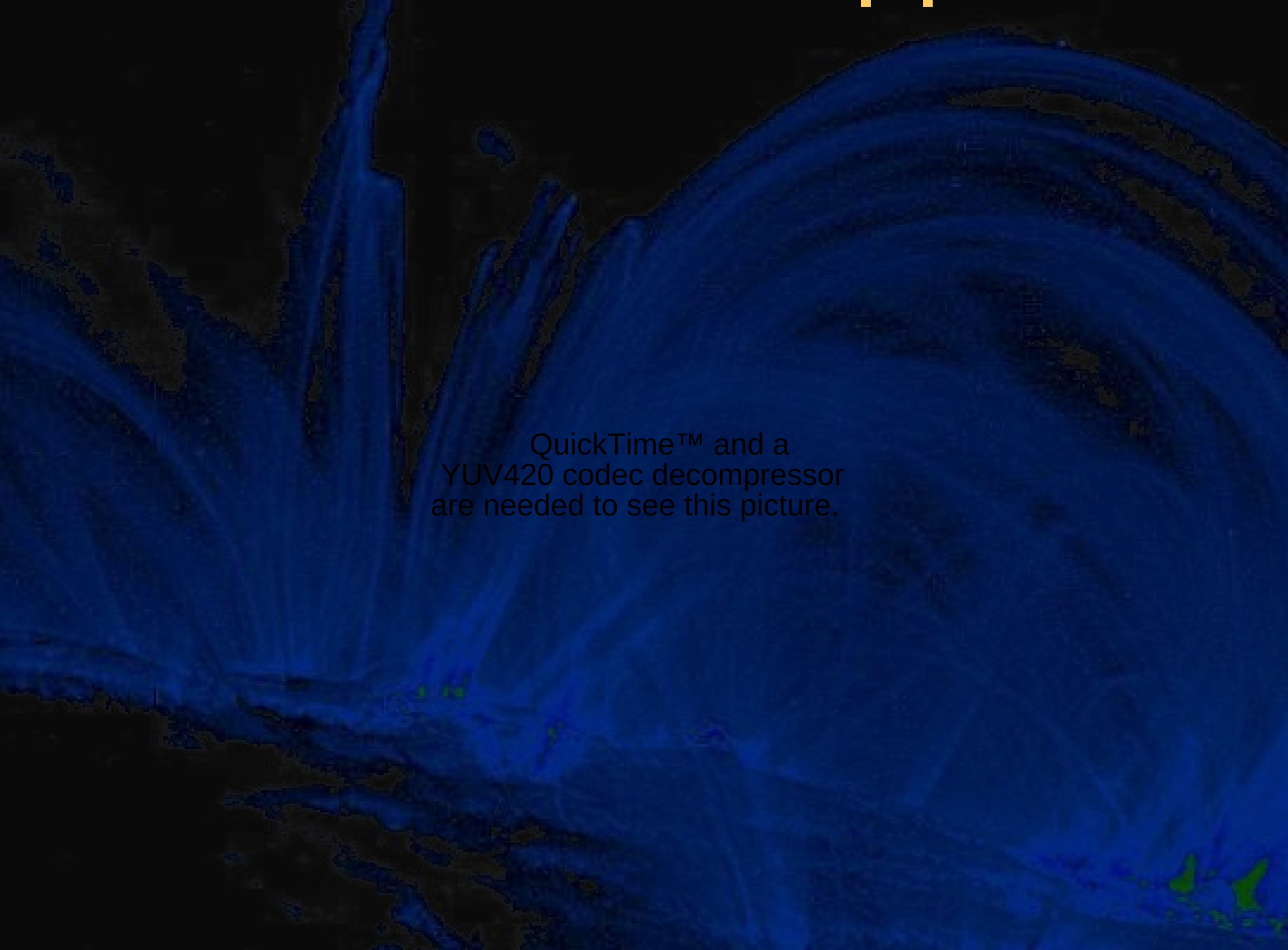
Testing *Ab Initio* Magnetised Outer Atmosphere Models



FK Com-like Flip-Flop model

- Magnetic structure computed from surface field predicted by "flip-flop" dynamo model (Elstner & Korhonen)
- X-ray Doppler Imaging will provide fundamental tests of dynamos and surface B field topology

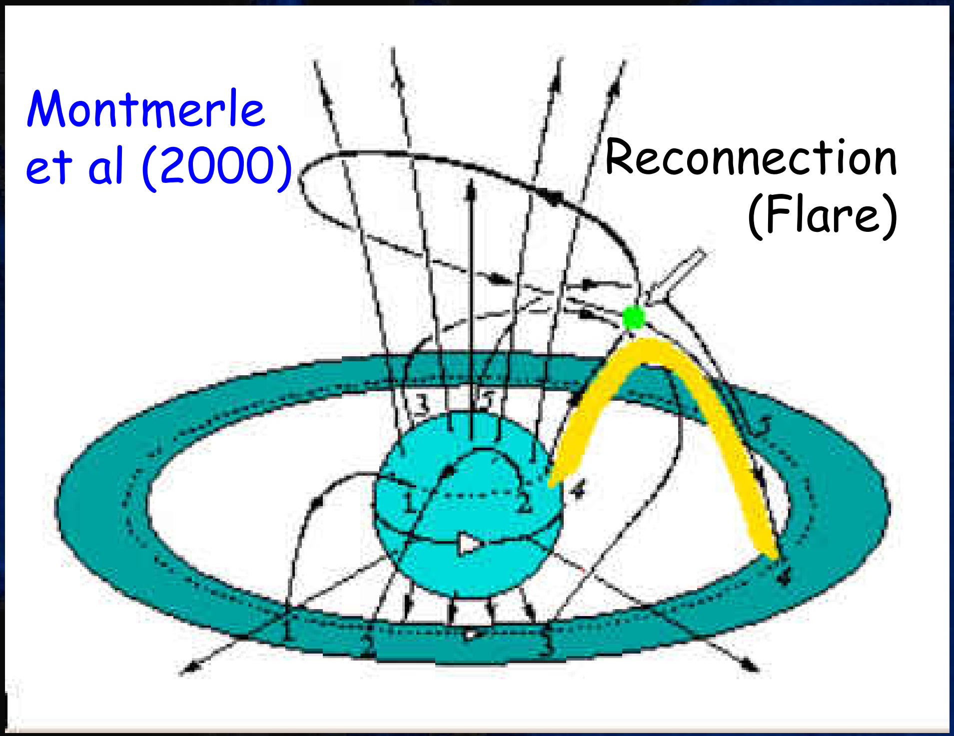
Model Doppler Shifts



Predicted velocities just within reach of Chandra for FK Com, but needs **larger area, higher resolution for Doppler image**

Doppler shift vs plasma T

Pre-Main Sequence Magnetospheres and Star-Disk Interactions



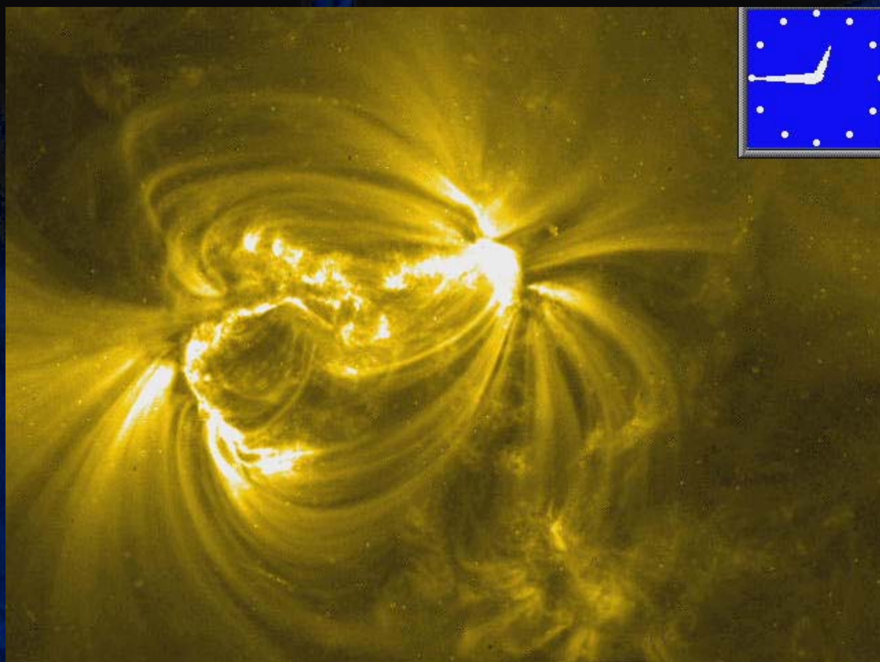
- Optical-UV evidence points to magnetospheric (spot) accretion rather than boundary layer
- Rotation periods of few days==> V~100km/s

With $\lambda/\Delta\lambda$ >2000 can begin to Doppler image magnetospheric structures and accretion

Magnetic Flares: Prototypes of Energy Lifecycles and Release (see R. Osten talk next)

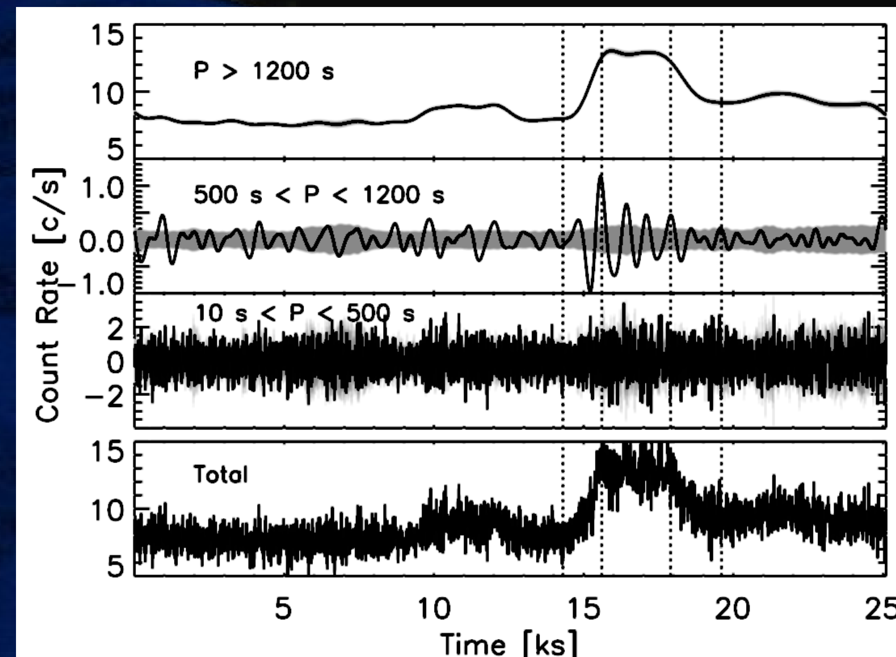
- Flares still not well-understood
- Observations often violate “standard model”
  - blueshifts from evaporated plasma too small
  - Soft X-rays sometimes seen *before* hard X-ray burst
- Con-X: photometric accuracy, time resolution, Fe Kα

Flaring loop oscillations



TRACE 171 A

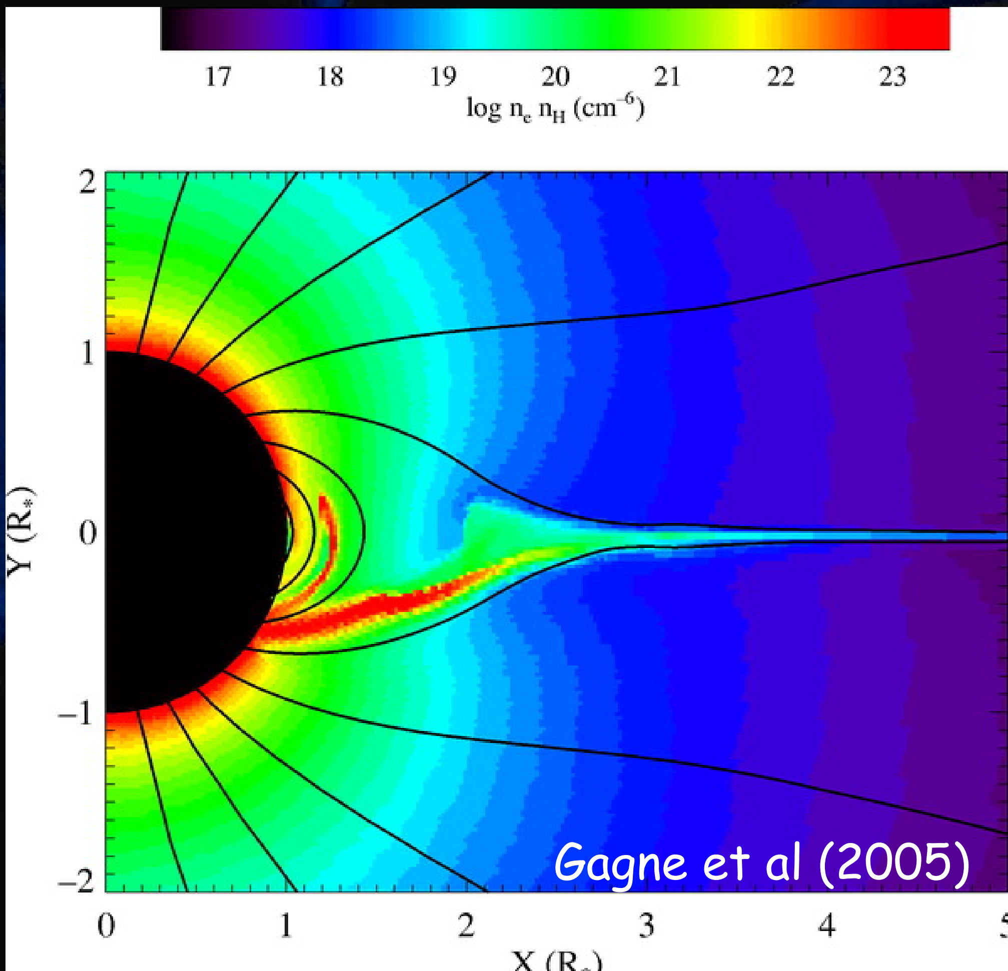
Longitudinal slow-mode wave



AT Mic Mitra-Kraev et al (2005)

- Loop oscillations triggered by flare events commonly seen in solar corona
- Oscillation frequency ==> B, L
- 1 event detected on stars, BUT signals will usually be small => **Con-X effective area** (=Yohkoh BCS for Sun)

Outflows and Shocks in Massive Stars



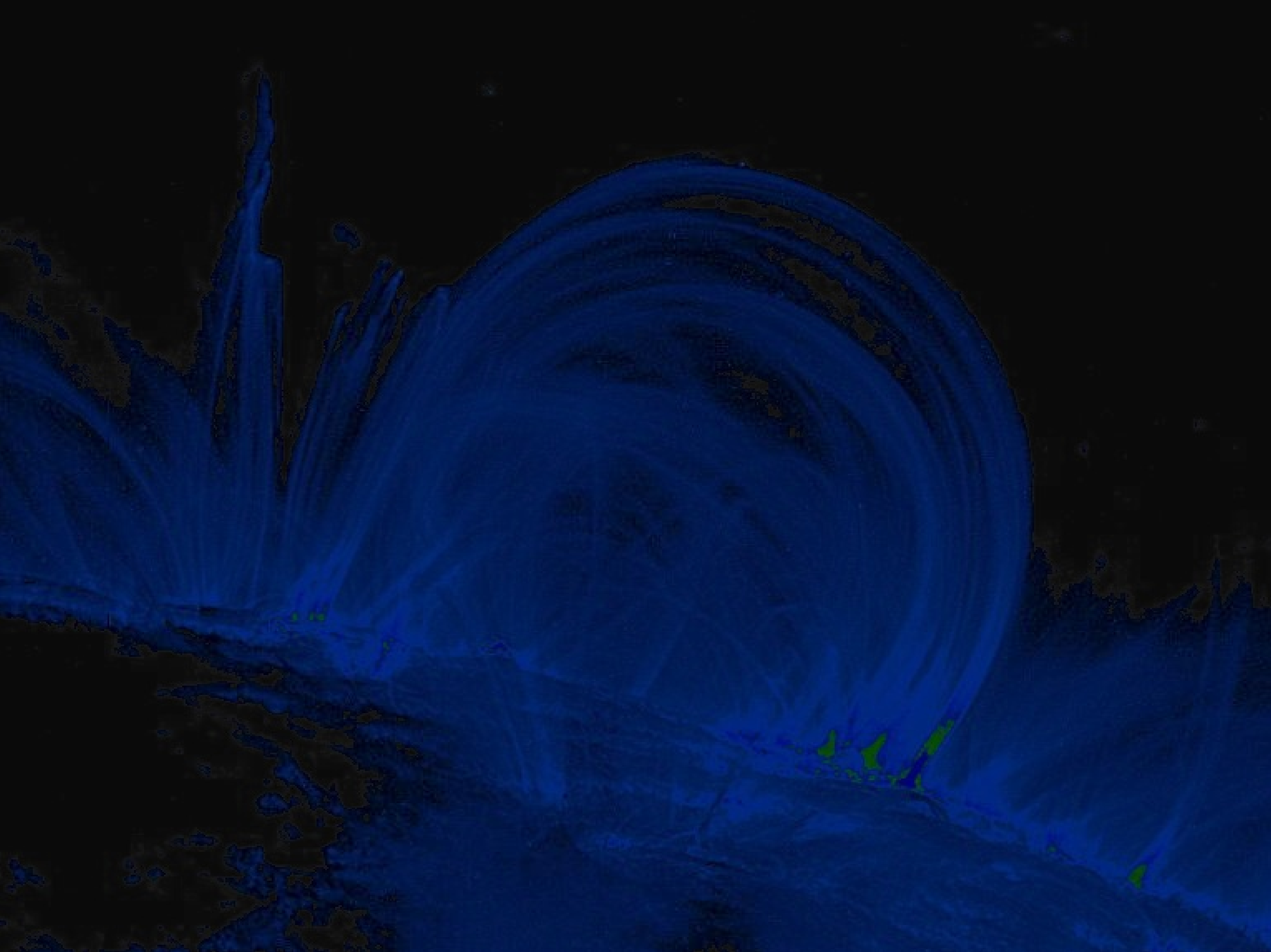
- Chandra+XMM spectra => magnetic confinement + heating of plasma in massive winds --> high density shock regimes (Schulz et al 2003, Gagne et al 2005)
- Seen in young stellar clusters
  - Impact on star/planet formation environment
- Colliding wind systems - eg M17 (Townsley et al 2004)
- <u>Currently **area-limited** to nearest star clusters</u>
  - Find these young objects in ultra-compact HII regions
  - Time-dependence from condensations, reconnection…

Important requirements for Con-X

- PSF --> 5"
  - Crowding in star forming regions; source confusion; asterospheric imaging, mass loss
- Spectral resolving power >~ 2000 **at low and high E**
  - Low E (down to He-like C): Protostellar Accretion and Jet physics; Doppler Imaging of quiescent coronae, accreting magnetospheres

Some Highlights of Con-X High Energy Stellar Physics

- Star formation: T Tauri Accretion, Jets, sites of massive star formation
- Protoplanetary Disks: heating, fluorescence mapping, abundances
- Doppler Imaging of magnetized plasma; magnetospheric accretion
- Magnetic reconnection flares



Scope of High Energy Stellar Physics

- Coronal heating
  - an outstanding problem in modern astrophysics
- Plasma astrophysics
  - stars provide comparatively well-understood laboratory for processes and conditions unattainable in the lab

Scope of High Energy Stellar Physics

- Magnetic field generation, evolution, dissipation
- Stellar Evolution
  - Mass loss, angular momentum evolution, interior mixing, binaries
    - CV's, novae, SN 1a

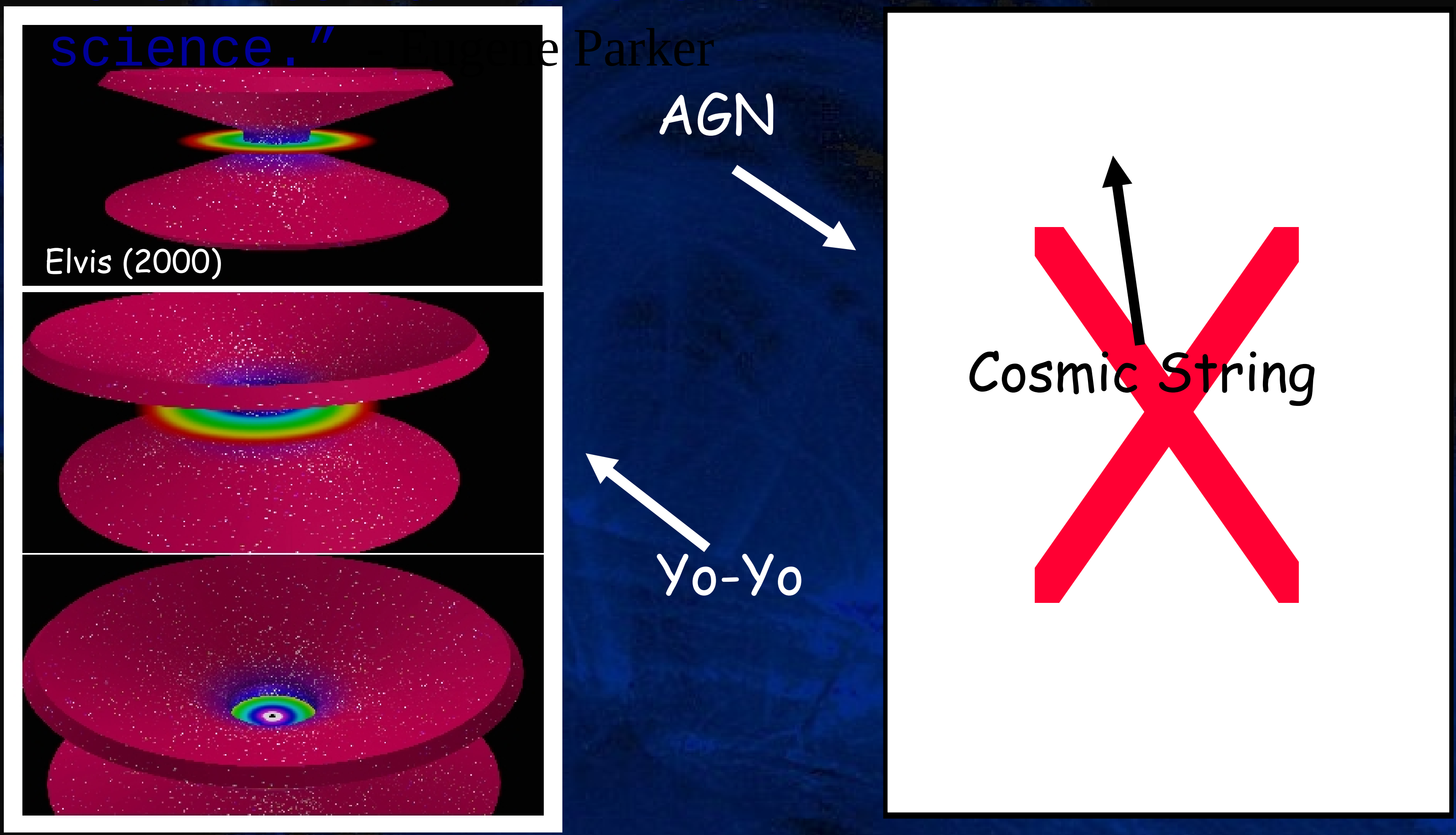
Scope of High Energy Stellar Physics

- Star and planet formation
  - Moderated by magnetic activity and energetic radiation
- Habitability of biospheres (through time)
  - Particle and photon irradiation

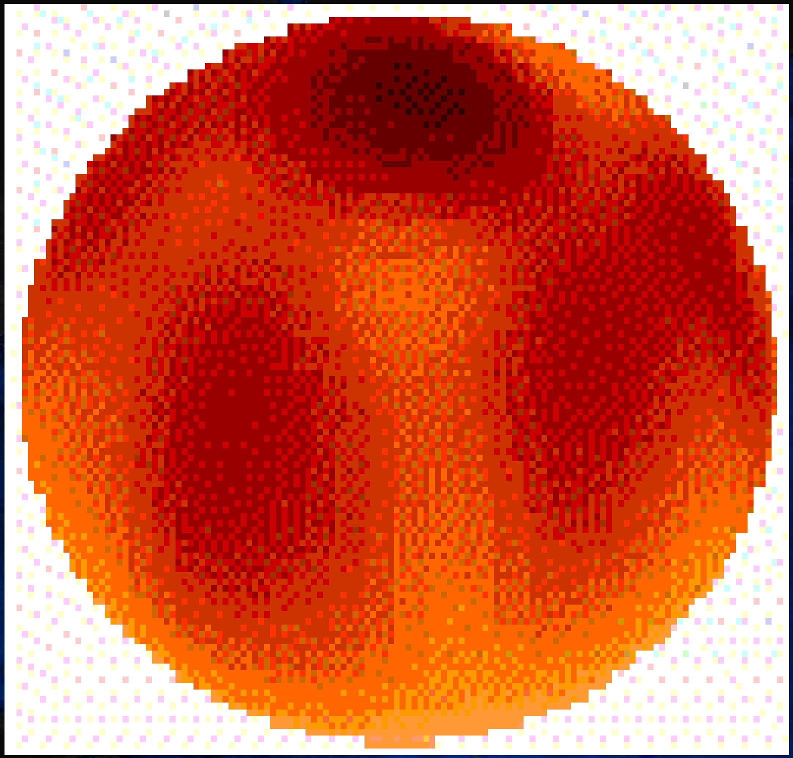
Scope of High Energy Stellar Physics

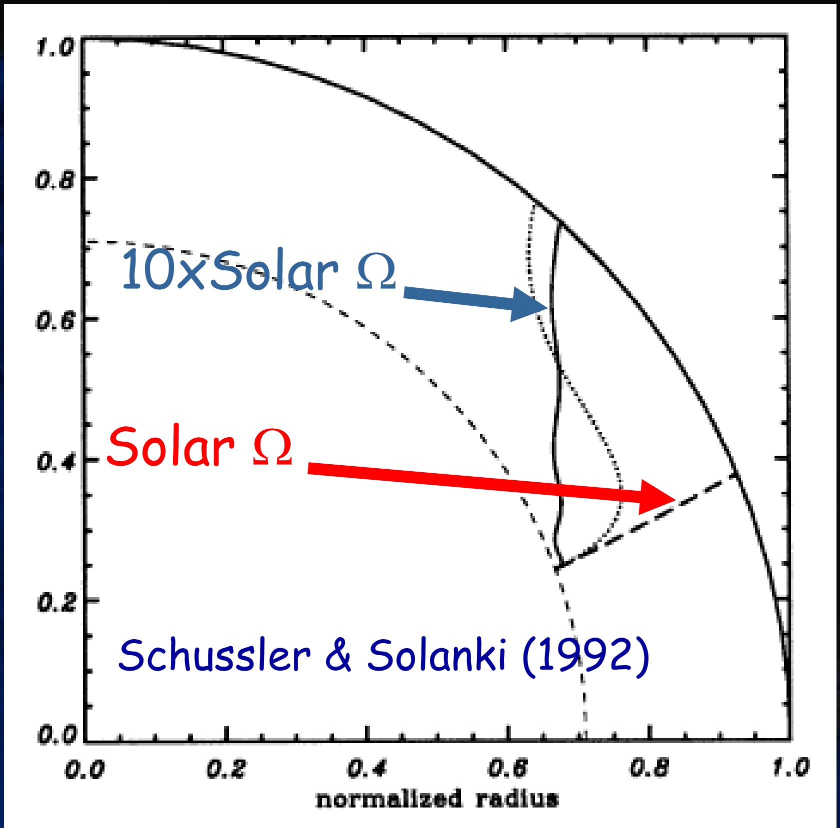
- Stars provide nearby prototypical examples of energetic astrophysical plasma processes found in the more distant and much less well-understood X-ray universe
  - accretion; jets; radiatively-driven outflows; magnetic reconnection, flares; chemical fractionation…

“The widespread astrophysical practice of declaring the nature of active unresolved celestial objects is more entertainment than science.” – Eugene Parker



Coronal Morphology - Like the Sun?



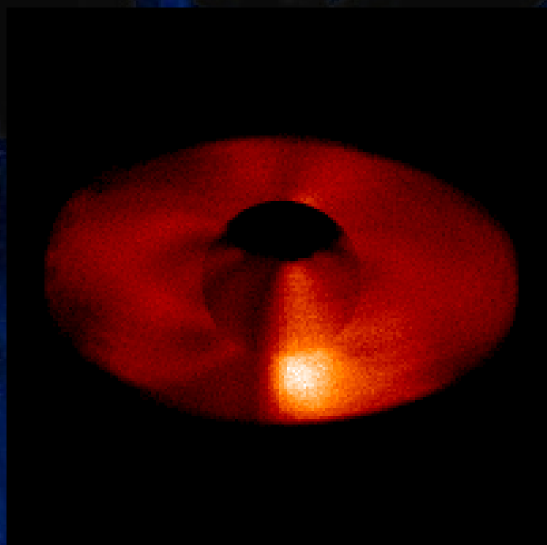


Visible light Doppler imaging of rapidly rotating active stars reveals large polar spots.

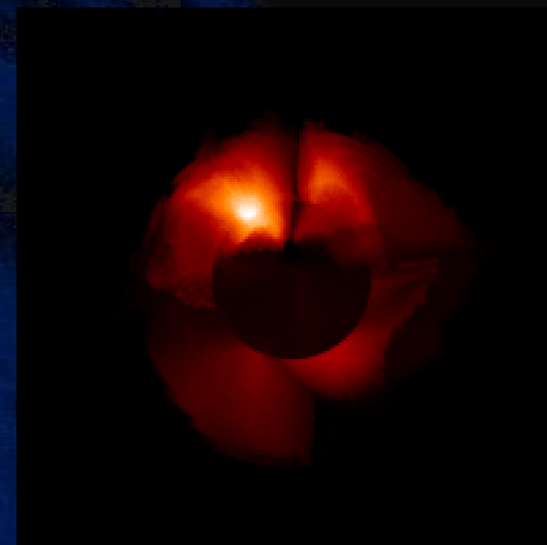
Magnetic flux migrates poleward due to Coriolis force and meridional flows (Schussler & Solanki 1992; Schrijver & Title 2001)

Con-X Coronal Doppler Imaging

AB Dor: ~25 Myr ZAMS K0 V; P_{rot}=0.5d; vsin i=95km/s



Models
By
K.Wood et al
(2002)



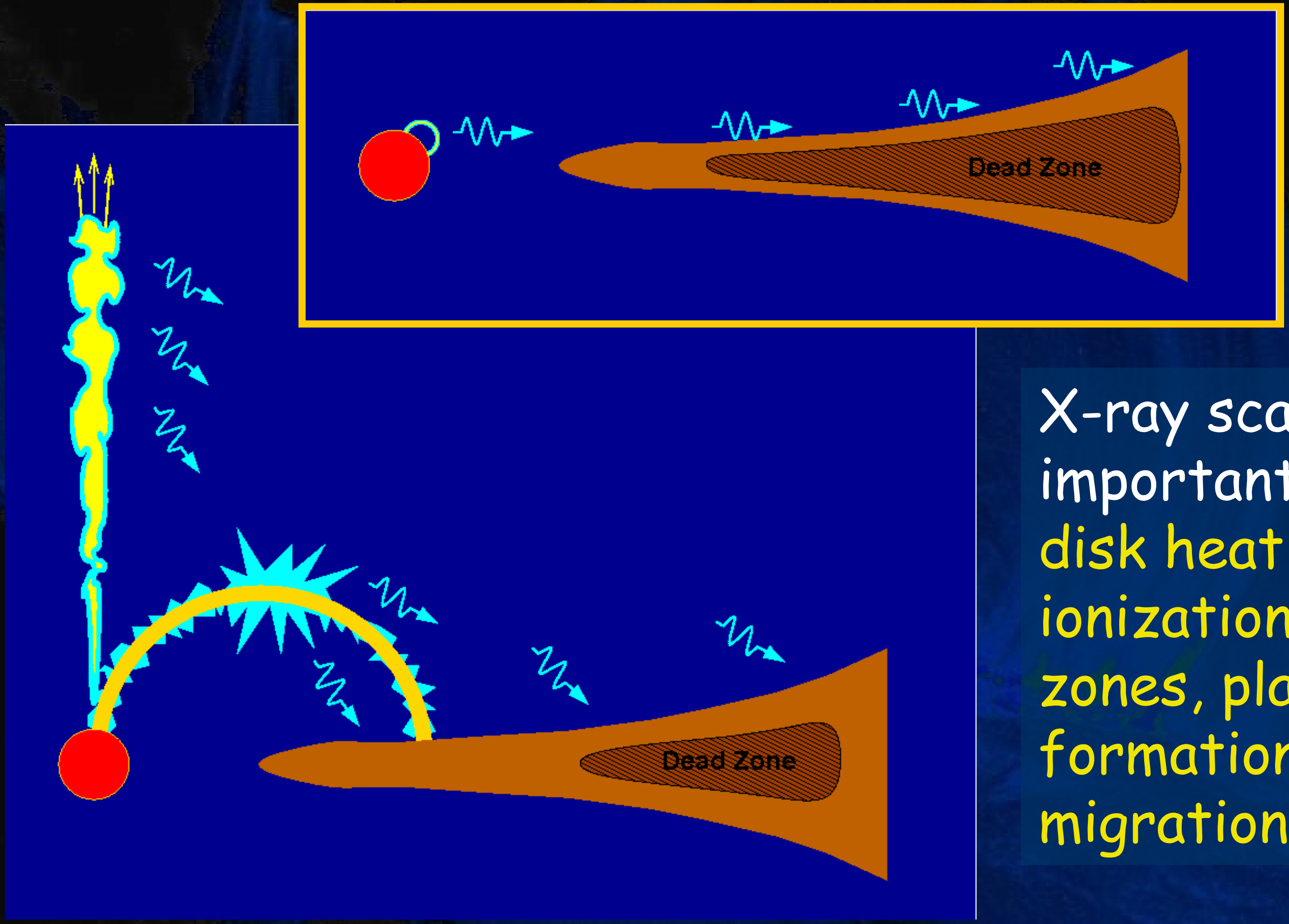
>200 km/s

45 km/s

Model with significant dipolar field suggested by Hα "slingshot prominences" (Collier Cameron et al. 1998)

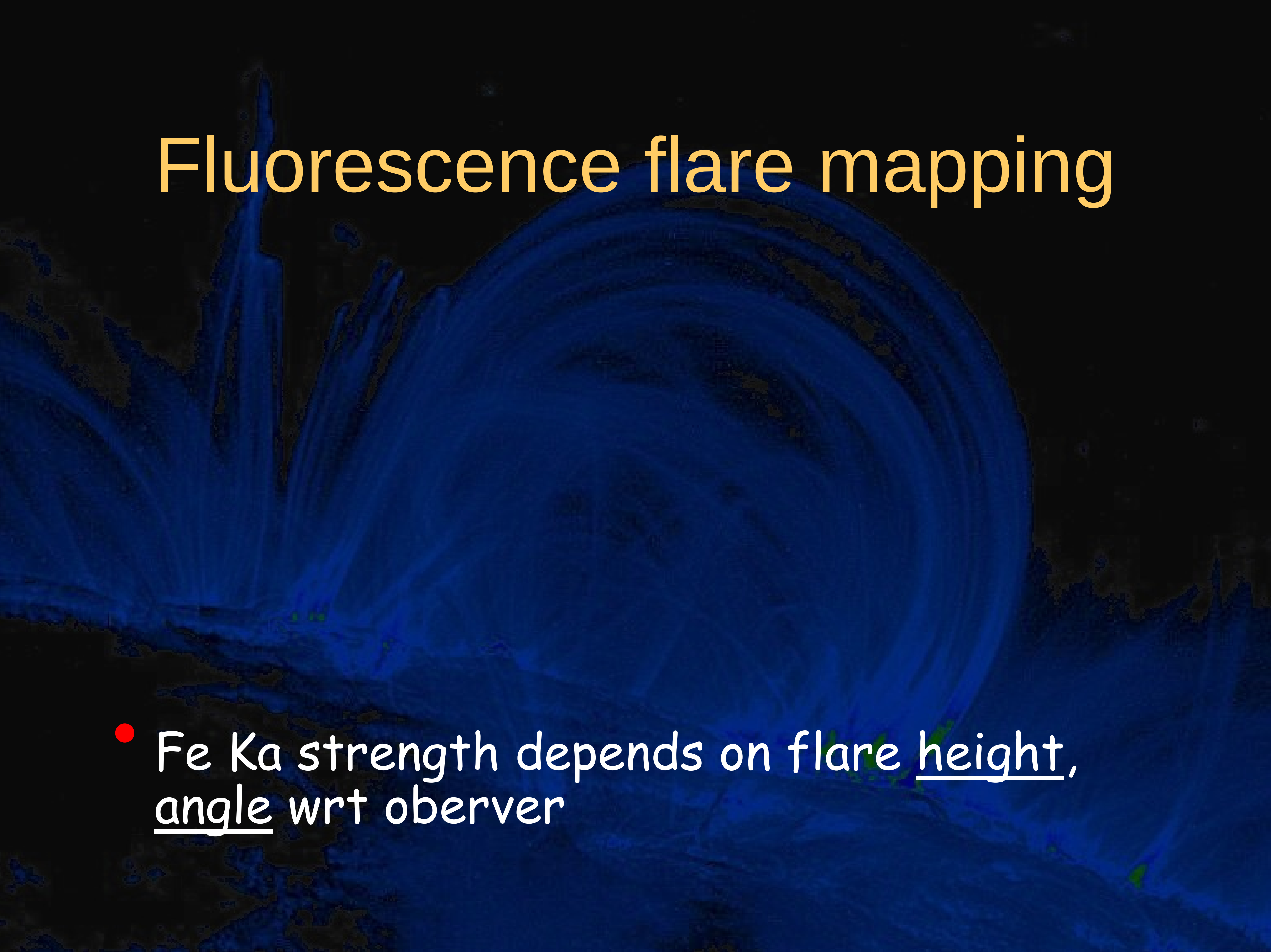
Optical Doppler imaging
And Coriolis force ==> B
Field emerges at poles

X-ray Emission Scale Height and Disk Heating+Ionization



X-ray scale height important for: disk heating, ionization, dead zones, planet formation, migration

Fluorescence flare mapping



- Fe Ka strength depends on flare height, angle wrt oberver